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DESIGN, DEVELOPMENT AND MANUFACTURE

OF STORAGE BATTERIES

FOR FUTURE SATELLITES

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REPORT NO. 3

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION - CONTRACT NO. NAS 5-509

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Alkaline Battery Division
GULTON INDUSTRIES, INC.,
Metuchen, New Jersey.

Prepared By: R. J. Dagnall
R. J. Dagnall [1961] 50p (0-1)
Project Engineer

Approved By: R. C. Shair
R. C. Shair
Director of Research

H. Thomas Staub
H. Thomas Staub
Asst. Project Engineer

J. H. Carter
J. H. Carter, Head
Development Section

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I. ABSTRACT

The best method of attaching cell covers to cell case has been established to be by heliarc welding. Tools and techniques have been perfected and are in operation. All welded, hermetically sealed cells are now being delivered. The development of the seal, from the old shear seal to the present configuration which permits all welded cells, is outlined.

The Pilot Plant equipment and processes are described. The Pilot Plant for assembly of hermetically sealed cells is practically complete equipment-wise. Industrial engineering techniques are being utilized to attain a steady flow of product through the line, and continued improvements are being made to reduce the rejection rate.

A derivation of equations for the heat flow within a cell is presented. Further data is presented on the electrical performance of the VO-6HS cells at high and low temperatures.

II. ESTABLISHMENT OF A PILOT LINE FOR FABRICATION OF HERMETICALLY SEALED CELLS (Phase II)

The design and establishment of a pilot production line, requires certain fundamental prerequisites. This line must serve to produce reasonable quantities of the cell specifically in mind at its conception, and it must also have a flexible capability of producing cells of other designs. The processes developed in the Pilot Plant will have considerable bearing upon the design of future cells. With this in mind, we proceeded to design and establish the best and most flexible line that we could.

The Pilot Plant as it exists at this moment, consists of essentially two separate but parallel lines joining for the final assembly. Since this is a Pilot Plant, equipment is grouped more for convenience in installation and segregation of types of operations rather than on a material flow basis. It is assumed that variations in cell construction will from time to time alter the material flow within the Pilot Plant.

The Pilot Plant area is located in the center of the new building of the Alkaline Battery Division of Gulton Industries, at Metuchen, New Jersey. This Pilot Plant area is completely enclosed and air-conditioned for the preservation of cleanliness, reduction of humidity, and control of temperature during the assembly of hermetically sealed cells for satellite applications.

The areas of this plant which are generating the most interest at this time are the manufacture of the ceramic-to-metal seal and the final closure of the cell. The basic equipment used to make and evaluate the seals are the Kinney Vacuum systems with their furnaces and the Veeco Mass Spectrometer Helium Leak Detector.

The Kinney KW-400 Vacuum system, with a 40 volt power supply and furnaces of our own design, has been the work-horse of the Pilot Plant for developing and producing ceramic-to-metal seals. This little unit was purchased first for its flexibility in performing the desired operations. Figure 1 is a picture of this machine. The one drawback to this machine is the vibration transmitted through the vacuum connections from the mechanical pump to the bed of the machine.

When it became evident that a larger machine was needed to handle anticipated demands for production, a Kinney P-2 Vacuum system best met our requirements and was purchased. This machine is presently assembled with two groups of 8 furnaces each, giving a total of 16 furnaces which can be loaded simultaneously and fired in rotation from two 40 volt power supplies. The actual flow of metal at each seal may be observed by the operator so that uniform products may be produced.

The development of the furnaces played an important part in obtaining good seals. Each furnace must give an even heat so that each part of the seal will flow at nearly the same time. Any shorting of coils by vacuum deposited materials from the sealing operation resulted in subsequent rejections on following seals. A covering for the heating element which shielded it from deposits and yet was not a substantial heat barrier was developed, and is now being used on all furnaces.

Each seal which passes a visual inspection must be carefully checked for leakage. The Veeco MS 9ABC Helium Leak Detector has proven to be an excellent machine for testing these seals. A seal, properly fixtured on this machine, can be tested for a leakage rate of the order of 10^{-10} cc of helium per second. The test procedures have been set up so that if there is any detectable leakage, even though it is of an order which could be tolerated, the seal is rejected. This eliminates seals which have flaws which could become enlarged under service conditions.

This Veeco leak detector, Figure 2, is also used to check the final closure of a cell. The entire cell may be fixtured under a bell jar which is connected to the detector. The cell is evacuated and back filled with helium. Anything that leaks from the cell to the bell jar is detected. Any cell that can pass this test with a pressure of 20 psia of helium within, is a good cell.

While the closure of a cell is of utmost importance, the elements within the cell are also important. A good container is of no value if the element within is capable of generating pressures that exceed the capacity of the container. To this end, two requirements must be met: the cell must be capable of recombining the oxygen formed at the positive plate during overcharge, and hydrogen evolution must be completely supressed during normal operation. To attain this objective, considerable care must be given to the formation cycle for the electrodes.

A formation pack consists of 8 positive plates and 9 negatives with a Dynel and Viskon separator wrapped as shown in Figure 3. By handling the plates in small groups, in this manner it is possible to handle large quantities and still assess the quality of all the plates. The formation setup is shown in Figure 4. If the capacity of any one plate is low, the entire pack containing this plate can be discarded with no great loss. Prior to formation, all plates are given a close inspection for any defects, particularly on the edges.

Following the formation cycles, the plates are thoroughly washed in a spray bath which removes all of the potassium hydroxide from the plates. The timing of this bath is critical since the plates must be washed clean, but must be removed from the wash before any corrosion occurs along the edges of the steel foundation of the plates. The plates are rushed from the wash into drying ovens where they are rapidly dried at a temperature of 50°C.

Until the plates are required for cell assembly, they are stored in plastic containers. Plate tabs are cut to length during this time, the positive tabs being one length, the negatives a different length. This makes it virtually impossible for electrode assemblies to be made in a mixed manner, or for the plates to be connected to terminals in improperly reversed polarity. The difference of plate length would certainly be spotted at one of the many inspections prior to the final closure of the cell.

The use of proper fixtures for cutting tabs, welding combs to packs, straightening combs after welding, and inserting the separator material; greatly facilitates the final assembly. Some of these are shown in Figures 5 and 6. All electrode stacks of VO-6HS cells are heavily compressed. This compression is necessary for the proper functioning of the cell, particularly on overcharge when oxygen is formed at the positive electrode but remains dissolved and transfers to the negative plate by diffusion through the flooded separator. The diffusion path should be as short as possible for maximum overcharge capability, and therefore the separator is compressed between the electrodes. The case is so designed that the electrode stack must be compressed to be inserted. While under maximum compression, the pack is checked for shorts.

With the pack inserted, the cell is now closed, using the new welding techniques and the Arcofix heliarc welding machine. Proper heat sinking protects the internal structure of the cell and the ceramic-to-metal seal.

The back-filling station of the Veeco MS9-ABC unit is now used to check the seal of the entire cell. The cell is fixtured, by means of the pinch tube, to the manifold outlet of the back-fill station, and tested as previously outlined. Successful cells are then filled with electrolyte, the amount being carefully controlled, and valve and gauge assemblies attached by means of a collet fitting on the pinch tube.

We now have what amounts to completed cells which must now be conditioned and tested electrically. For this purpose, a 50 volt 300 ampere power supply has been installed and a cycling panel is being completed in the Pilot Plant. This panel, when completed, will cycle any contemplated size cell automatically. At present some elements are being used to cycle cells until the complete unit can be placed into operation. The cells shown in Figure 7 were cycled using this equipment.

The final steps in the manufacture of the cells consists of closing the pinch tubes, removing the gauge unit, welding the pinch tube tight, and making final electrical tests and leak checks prior to shipment.

The two most critical pieces of equipment in the Pilot Plant are the Kinney P2 Vacuum System, and the Veeco MS 9-ABC Leak Detector. If there should be a failure of the former piece of equipment, production of seals would be very seriously limited, since the PW 400 unit could not make a tenth of the quantity the P2 can make. The leak detector, due to the many inspection operations required of it, is being used at maximum capacity now, and a supplemental unit, possibly an MS 9AB unit, will soon be required to meet the work load and to provide back up in case of failure on the primary unit.

III. FABRICATION OF CELLS (PHASE 1)

To date, a total of 78 VO-6HS type cells have been delivered to NASA. Table I lists the electrical characteristics recorded for delivered cells. Of this total, 41 were delivered to fill a need for cells to evaluate electrically, and were known to have imperfect seals. The tops of these cells were potted in epoxy to give as tight a seal as possible for the tests.

Of the balance of the cells delivered, 25 have welded closures and are functioning as hermetically sealed cells, and 12 are of soldered type construction, some of which have leaked.

At the time of this writing, additional welded cells are on final electrical test. When these cells have been checked out by the initial cycling, overcharge tests and short tests, the tubes will be pinched off to remove the pressure gauges and then pinched and welded closed, giving a truly all welded cell.

TABLE I.

Electrical History of VO-6HS Cells Delivered to NASA

NOTE: The cells having a suffic P on the serial number were not considered hermetically sealed, but were delivered to fill a need for cells for prototype evaluation of electrical characteristics.

Cell	Overcharge 500 ma		Capacity Check	Overcharge 500 ma		No. of	Electrical Short Test
Serial No.	Volts	PSI	To 1.0 V	Volts	PSI	Cycles	Voltage
120 P	1.495		8 amps 6.8 AH			11	
133	1.495	36	3 " 8.04 AH	1.430	43	25	
135	1.461	22	3 " 7.53 AH	1.460	37	25	
136	1.461	44	3 " 7.68 AH	1.440	24	25	
141	1.410	24	3 " 7.23 AH	1.440	24	25	
144	1.415	24	3 " 7.23 AH	1.430	18	25	
155 P	1.495	3	3 " 6.99 AH	1.495	2	12	1.20
156 P	1.495		8 " 6.0 AH			11	
157 P	1.495		8 " 6.0 AH			11	
158	1.425	17	3 " 6.48 AH	1.42	12	25	1.31
160 P	1.495		8 " 6.0 AH			11	
161	1.495	75	3 " 6.99 AH	1.44	35	25	1.31
163 P	1.495		8 " 6.4 AH			11	
168	1.495	14	8 " 6.48 AH			24	
170 P	1.400		8 " 6.3 AH			11	
171	1.495	75	3 " 6.48 AH	1.44	30	25	1.31
174 P	1.400		8 " 6.0 AH			11	
182 P	1.495	5	3 " 7.23 AH	1.60	5	12	1.21
183 P	1.50	5	3 " 6.09 AH	1.42	2	12	1.24
185 P	1.47	21	3 " 6.0 AH	1.45	8	12	1.24
187 P	1.575	22	3 " 6.75 AH	1.525	13	12	1.20
189 P	1.47	8	3 " 6.3 AH	1.48	5	12	1.21
190 P	1.495	2	3 " 7.23 AH	1.495	0	12	1.20
191	1.495	5	8 " 6.0 AH			24	
194 P	1.505	27	3 " 6.75 AH	1.505	5	12	1.20
195 P	1.450		8 " 6.2 AH			11	
196 P	1.450		8 " 6.08 AH			11	
197 P	1.60	5	3 " 7.23 AH	1.60	5	12	1.20
198	1.495	8	3 " 6.7 AH	1.498	9	12	1.20
201 P	1.495	35	3 " 7.23 AH	1.495	35	12	1.20
204 P	1.495		8 " 6.64 AH			11	
208 P	1.50	45	3 " 7.23 AH	1.50	50	12	1.20
210 P	1.60	5	3 " 7.23 AH	1.60	5	12	1.20
212 P	1.46	35	3 " 7.50 AH	1.49	27	12	1.23
214 P	1.45	12	3 " 7.50 AH	1.50	20	12	1.23
215 P	1.45	45	3 " 7.23 AH	1.45	45	12	1.20
216 P	1.495		8 " 6.64 AH			11	
218 P	1.54	20	3 " 6.75 AH	1.51	13	12	1.23
219	1.41	33	3 " 7.5 AH	1.43	16	24	1.25
224 P	1.48	5	3 " 6.75 AH	1.42	5	12	1.20

TABLE I. - Cont'd.

Cell Serial No.	Overcharge Volts	500 ma PSI	Capacity Check To 1.0 V	Overcharge Volts	500 ma PSI	No. of Cycles	Electrical Short Test Voltage
225 P	1.39	17	3 amps 6.20 AH	1.45	11	12	1.20
227 P	1.50	43	3 amps 7.74 AH	1.50	12	12	1.25
229 P	1.46		3 " 6.99 AH	1.50		12	1.25
230 P	1.54	5	3 " 7.59 AH	1.49	7	12	1.25
232	1.51		3 " 6.9 AH	1.45	15	24	1.25
233 P	1.50		3 " 7.08 AH	1.50		12	1.25
236	1.40		3 " 6.48 AH	1.46	5	24	1.25
240 P	1.42	47	3 " 7.29 AH	1.43	44	12	1.23
250	1.45	21	3 " 7.5 AH	1.50	29	24	1.285
251 P	1.52		3 " 6.75 AH	1.50		12	1.25
262	1.40	0	3 " 7.4 AH	1.425	20	10	1.20
263	1.50	42	3 " 6.5 AH	1.425	20	10	1.20
264	1.50	7	3 " 7.4 AH	1.425	24	10	1.20
265	1.495	12	3 " 6.2 AH	1.425	21	10	1.20
266	1.495	13	3 " 6.2 AH	1.425	24	10	1.20
267	1.50	10	3 " 6.9 AH	1.45	43	10	1.20
268	1.40	23	3 " 6.9 AH	1.45	24	10	1.20
271	1.40	-10	3 " 6.8 AH	1.425	22	10	1.20
273	1.50	38	3 " 6.5 AH	1.43	18	10	1.20
274	1.40	0	3 " 6.5 AH	1.425	22	10	1.20
275	1.50	31	3 " 6.2 AH	1.425	26	10	1.20
276	1.50	12	3 " 6.8 AH	1.45	8	10	1.20
278	1.40	-5	3 " 7.5 AH	1.425	39	10	1.20
279	1.40	10	3 " 7.3 AH	1.45	19	10	1.20
280	1.40	-8	3 " 6.7 AH	1.425	9	10	1.20
282	1.45	25	3 " 7.8 AH	1.50	31	10	1.20
283	1.45	12	3 " 6.9 AH	1.45	24	10	1.20
284	1.45	45	3 " 6.9 AH	1.45	4	10	1.20
285	1.45	56	3 " 7.9 AH	1.45	8	10	1.20
286	1.45	24	3 " 6.9 AH	1.45	37	10	1.20
287	1.45	20	3 " 6.9 AH	1.425	37	10	1.20
288	1.45	61	3 " 7.6 AH	1.425	4	10	1.20
289	1.50	18	3 " 7.3 AH	1.45	14	10	1.20
291	1.50	6	3 " 7.3 AH	1.45	10	10	1.20
292	1.45	17	3 " 6.4 AH	1.45	15	10	1.20

Those cells serial numbered from 262 - 292 are welded and perfectly hermetically sealed and tested. They have passed every quality control check point and have been thoroughly checked out electrically as well as mechanically before delivery.

At the beginning of this contract, the Alkaline Battery Division of Gulton Industries, Inc., in cooperation with the Ceramics Division, had developed a ceramic-to-metal seal and succeeded in incorporating this seal into a nickel-cadmium cell. When the first attempts were made to produce a quantity of sealed cells, this seal was found to have some shortcomings. The ceramic shape required for this seal had a sharp step which resulted in a stress concentration point. When tensile and shear stresses were exerted upon the ceramic, during the final closure of can to case, the ceramic was damaged.

Therefore, steps were taken to modify the design of the seal. A new seal design was conceived, which resulted in compressive prestressing of the ceramic as the seal was generated. An end condition was discovered in which the compressive stress of the terminal to the ceramic was resulting in a shear load which set up fractures in the ceramic. A minor change cleared up this difficulty, and we had the basic seal upon which to build the cell.

The sealing process requires meticulous care in the assembly of parts and the placing of sealing elements. This imposes a great responsibility upon the technician making the seal assembly to repeatedly assemble each unit with the required care and cleanliness. It has been demonstrated that a good technician can consistently produce seals of very high quality.

The next problem encountered was in the making of the final closure of the cell. Due to the small size of the VO-6 HS cell, the joint between the cover and the case comes into relatively close proximity with the ceramic-to-metal seal at various points on its circumference. The result was that uneven stresses induced in the cover by the operation of welding the cover to the case, were destroying the ceramic-to-metal seal.

Three possible solutions to this problem were apparent; the joint could be removed from the area of the seal, heat sinking could keep the heat away from the seal, or a lower temperature method of sealing the cells could be found. The first method was ruled out because it would add a substantial amount of weight to the cell. The second method was ruled out because it was considered too difficult to obtain adequate heat sinking in the areas involved. This left the last method, namely, to find a solder with sufficient strength and resistance to electrolyte.

Many materials were screened to find a solder with suitable resistance to potassium hydroxide. Metals and solder companies were contacted and the field service and top technical consultants of the major companies were called in for consultation. The field narrowed to a cadmium-silver solder or a lead-silver solder. The cadmium solder being a harder solder was selected. An attempt was made to attach the seal to a separate ring which could be soldered to the cover after the cover had been joined to the case by welding. This configuration was referred to as the floating type seal. However, due to certain tolerance conditions and the flowing characteristics of the solder, the desired joint could not be made consistently.

The next step was to make the seal directly to the cover, and then solder the whole cover into place. Enough success was achieved with early models of this configuration to encourage further development along this line. The cover was redesigned to accommodate the new method of joining to the cover. A number of dummy cells were made and subjected to leak and pressure tests with significant success.

The assembly of cells proved to be a different matter. The flux required to make the solder joint proved harmful to the electrode. By exercising very diligent care in the soldering operation, it was possible to minimize the effect, and produce a suitable cell. The handling of the solder proved to be a major problem since it flowed very poorly, and the temperature at which it flowed, was very close to the temperature at which it vaporized. The net result was that, while some good cells could be made, the reject rate was exorbitant. In a large number of cases, the ceramic-to-metal seal was being destroyed by the rigors of making the final closure. A Lepel induction heater was employed to try to limit the amount of heat, and the locality of the heating. Technical consultants from Lepel Company and Handy and Harman Company were called in to perfect the process. The closeness of the flow temperature of the solder to the vaporization point created problems. The fit of the cover to the case was very critical, so that this operation was never able to turn out consistently good cells which would withstand cycling and vibration testing.

A few cells were made with the lead silver solder, which behaved better than the cadmium solder as far as flow was concerned, but proved to be too weak for reliable joints when the cells were tested for repeated shock and vibration.

During this period of experimentation to devise a good closure method for the can to cover joint, the cells were shock acceleration and vibration tested under electrical load. No discontinuities of electrical performance were observed, no resonances were observed, and the ceramic-to-metal seal itself stood up very well. Shock tests were run as high as 50 G.

This brings us to the current state of the art of making hermetically sealed cells. Refinement of the techaiques of making the ceramic-to-metal seal, and the aquisition of a heliarc welding machine having excellent control of the arc, have made the production of an all welded cell an accomplished fact.

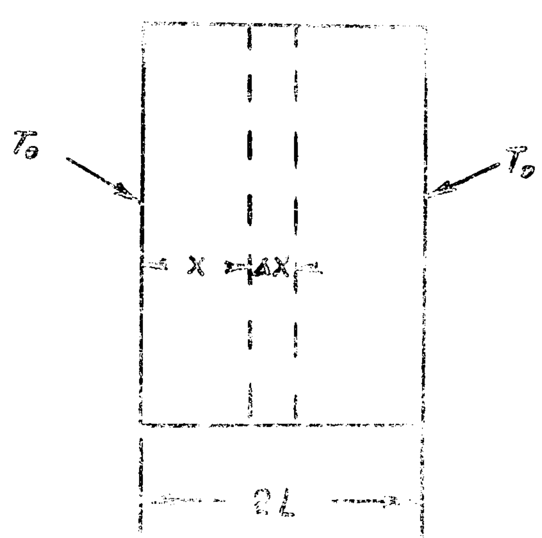
The welding operation appeared most feasible, but technique and tooling were necessary. The Linde Airco Labs were contacted for consultation. An expert heliarc welder was retained on a consulting basis to design and fabricate jigs and fixtures for holding and cooling the cells during weld. The welding consultant also trained our operators to make a rapid and perfect weld. During August, Messrs. Wayne Stafford and Joseph Albert of Space Technology Laboratories visited us to observe the welding operation. Mr. Albert is a metallurgist and a welding expert, and he was thoroughly convinced that our approach to the problem was sound, and that the resulting weld appeared to be satisfactory. Several welds were cut open in cross section, and examined and found to be sound.

IV. RESEARCH AND DEVELOPMENT
(Phase III)

A. Heat Transfer

Studies of heat transfer and thermal conductivity have been started. The following is a derivation of the heat transfer equation as applied to cells of the general configuration of the Gulton hermetically sealed cell.

ASSUME UNIDIMENSIONAL HEAT TRANSFER



Heat Conducted Through Left Face During Time $\Delta\theta$	+	Heat Generated By Sources In Element During Time $\Delta\theta$	=	Heat Conducted Through Right Face During Time $\Delta\theta$

$$(1) \quad -KA \left.\frac{dT}{dx}\right|_{x} \Delta\theta + \dot{q}\,(A\,\Delta x)\,\Delta\theta = -KA \left.\frac{dT}{dx}\right|_{(x+\Delta x)} \Delta\theta$$

where $\dot{q} = \dfrac{\text{Heat Source Strength}}{\text{Unit Volume, Unit Time}}$

Using The Mean Value Theorem

$$f(x+\Delta x) = f(x) + \frac{d}{dx}(f(x))_M \Delta x$$

where M is located between (x) and (x + Δ x)

$$\therefore \quad \frac{dT}{dx}\Big|_{x+\Delta x} = \frac{dT}{dx}\Big|_{x} + \left[\frac{d}{dx}\left(\frac{dT}{dx}\right)\right]_M \Delta x$$

Substituting into Equation (1)

$$-KA\frac{dT}{dx}\Big|_x \Delta\theta + \dot{q}\,(A\,\Delta x)\,\Delta\theta = -KA\frac{dT}{dx}\Big|_x \Delta\theta - KA\frac{d^2T}{dx^2}\,\Delta x\,\Delta\theta$$

$$\therefore \quad \dot{q} = -K\frac{d^2T}{dx^2} \qquad \text{or} \qquad \frac{d^2T}{dx^2} = -\frac{\dot{q}}{K}$$

Integrating

$$\frac{dT}{dx} = -\frac{\dot{q}}{K}\,x + C_1$$

Integrating Again

(2) $$T = -\frac{\dot{q}}{2K}\,x^2 + C_1\,x + C_2$$

Boundary Conditions

a. $T = To, \quad x = 0$

b. $T = To, \quad x = 2L$

Substituting a into (2)

$$To = C_2$$

$\therefore$ Equation 2 is

(2a) $$T = -\frac{\dot{q}}{2K}\,x^2 + C_1\,x + To$$

Substituting (b) into (2a)

$$To = -\frac{\dot{q}}{2K}(2L)^2 + C_1\,2L + To$$

Substituting C_1 and C_2 into Equation (2) and rearranging terms

$$T - To = \frac{q L^2}{2 K} \left(2 \frac{x}{L} - \frac{x}{L}^2 \right)$$

which is a parabolic equation indicating the temperature distribution across the cell is a parabola with the apex at the middle, x = L.

$$AT \quad x = L, \quad \frac{dT}{dx} = 0$$

$$T \text{ internal} - To = \frac{q L^2}{2 K}$$

or

$$(3) \qquad K = \frac{q L^2}{2 (T \text{ internal} - To)}$$

Where K = Thermal Conductivity $\frac{BTU}{Hr. \; ^oF \; Ft.}$

L = Distance (Ft)

T internal = Internal Cell Temperature (^oF)

To = Mean Skin Temperature (^oF)

q = Internal Heat Generation $\frac{BTU}{Hr. \; Ft^3}$

Using equations (3 and the analogy of heat flow and current flow, one may obtain the following equations which determine the amount of heat flowing in the three mutually perpendicular planes of the cell.

$$4\ (a) \quad \dot{q}_x = \frac{\frac{1}{L_x}}{\frac{1}{L_x^2} + \frac{1}{L_y^2} + \frac{1}{L_z^2}} \quad \dot{q}$$

$$4\ (b)\quad \dot{q}_y = \frac{\frac{1}{L_y^2}}{\frac{1}{L_x^2} + \frac{1}{L_y^2} + \frac{1}{L_z^2}}\ \dot{q}$$

$$4\ (c)\quad q_z = \frac{\frac{1}{L_z^2}}{\frac{1}{L_x^2} + \frac{1}{L_y^2} + \frac{1}{L_z^2}}\ \dot{q}$$

Beside the study of the heat transfer directly from the cell, means of transferring heat from the cells within a battery pack are being studied. The use of aluminum sheets of approximately 1/32 inch thick, coated in such a manner as to make them good electrical insulators but not reduce the thermal transfer too greatly, have shown great promise in transferring heat. These sheets were placed between cells in lieu of the regular insulators, but connected to a heat sink, reduced the operating temperature of an internal cell as much as 40°F.

Some of the heat transfer analysis for sealed cells is already being applied to the development of a 20 ampere-hour battery for the OAO power supply which is a NASA project, being guided by Grumman Aircraft Engineering Corporation, who has subcontracted to Gulton Industries for the battery.

For the 20 ampere-hour cells, Figures 8 and 9 show a plot of internal cell temperature versus time, as well as electrical cell characteristics versus time for ambient conditions of 83°F and 104°F, respectively. It can be seen in both cases, that during the charging cycle, the internal cell temperature of the cell remains constant. However, once the cell is fully charged, the internal temperature begins to increase, and the cell goes into an overcharge condition at the 8 ampere charge rate. Looking at the electrical characteristics, one again sees a constant terminal voltage until a state of overcharge is reached, at which the terminal voltage begins to increase and reach a plateau at a higher voltage. When the cells were placed on the 1.4 ampere overcharge, the internal temperature decreased to a constant value, and remained there for the remainder of the test cycle.

Three dimensional thermal gradients were constructed for the cell during the charge, overcharge, and discharge segments of the cycle, for both ambient conditions. (Figures 10 - 21)

From the figures it may be seen that the lower two-thirds of the cell runs hotter than the upper one-third. This is evident from the fact that in the upper third of the cell, there are no cell plates, and therefore no chemical reaction takes place in this portion of the cell.

B. <u>Electrical Characteristics Of The VO-6HS Cell</u>

The VO-6HS cells previously reported in Report No. 1 under this contract have continued to be cycled and at this time have reached the 1700 cycle point with 30% depth of discharge for each cycle. Cell capacity has not deteriorated. Cell pressure has not increased and end-of-charge voltage and end-of-discharge voltage are still at quite acceptable values. This data is shown in Figure 22.

Additional electrical data has been obtained at high and low temperatures. Figure 23 shows the overcharge voltage characteristics at 48°F and 120°F superimposed on the original data sheet showing this characteristic at 77°F. Studies of cell performance at low temperatures indicate that charge acceptance and continuous overcharge capability are reduced. At high temperatures 120°F charge efficiency is reduced, and recharge charge can only be accomplished at high rates (C rate) or for impractically long periods of time at low rates (90 hours at c/10 rate). Further study of extreme temperature operation and R & D on methods to improve cell performance at these low temperatures appear to be worthwhile future projects.

V. CONCLUSIONS

1. Fabrication Of Cells

The elimination of solder and the redesign of cell components for welded construction appears to have eliminated all major barriers to the production of completely sealed cells.

2. Establishment Of A Pilot Line

The major components of the pilot line are in place. Refinement of certain techniques and equipment to increase production and reliability will continue.

3. Research And Development

A method of analyzing a cell configuration for optimum heat transfer is available. After the method is substantiated by experimental results, we will have a useful tool to use in determining optimum configurations of cells. Investigation of the problems involved in removing heat from the inside of a cell to a heat sink has resulted in reduced temperature gradients within a battery configuration.

VO-6HS cells have been continuously cycled in a 30% depth of discharge for over 1700 cycles. Overcharge data at $40^{o}F$ indicates a reduced capability at this low temperature. Data was also collected at $120^{o}F$.

VI. PROGRAM FOR NEXT PERIOD

PHASE I. Fabrication Of Cells

More all welded cells will be delivered. Thirty-five of these cells are to be delivered to the Goddard Space Flight Center by September 30, 1961.

The design of the VO-6HS cell will be studied further, and any changes that will improve the fabrication, function, or reliability of these cells will be incorporated in the production cell.

PHASE II. Establishment Of A Pilot Line

Consideration is being given to the problem of machine capacities and backup machines to cover possible breakdown of essential equipment. Further study of the production techniques will be made to increase production capability and reliability.

PHASE III. Research And Development

Experimental configuration of the derived heat transfer equations will be obtained. Further analysis of the mechanisms of heat transfer in sealed cells will continue.

Evaluation of the electrical characteristics of the VO-6HS cell will continue, particularly at high and low temperatures and on continuous cycle with a 90 minute cycle. Studies will be made of charge efficiency at high temperatures.

PHASE III. (Continued)

Thin plate cells will be studied and prototypes built to determine if 20 watt-hours per pound is achievable with this geometry.

Evaluation will be done at 165°F for separator materials of potential interest.

VII. PERSONNEL

NAME	HOURS WORKED
R. C. SHAIR, Director of Research	48
H. N. SEIGER, Section Head Physical Research	2
R. J. DAGNALL, Mechanical Engineer, Project Engr.	263
H. T. STAUB, Mechanical Engr., Asst. Proj. Engr.	392
A. CHERDAK, Electrical Engineer	46
R. FLECKENSTEIN, Jr. Electrical Engineer	368
L. ANDREWS, Draftsman	49
J. ALFIERI, Jr. Mechanical Engineer	424
D. MOWEN, Jr. Mechanical Engineer	432
J. LO MONTE, Production Engineer	492
ASSEMBLY LABOR	2133
C. HENNINGSEN, Jr. Electrical Engineer	16
M. ROBINS, Industrial Engineer	276
A. KOWALSKI, Jr. Electrical Engineer	40
J. CARTER, Section Head Development	104
Total	5085

Quarterly Direct Labor Cost $13,093

rkw

FIG. 1

FIG. 2

FIG. 3

FIG. 4

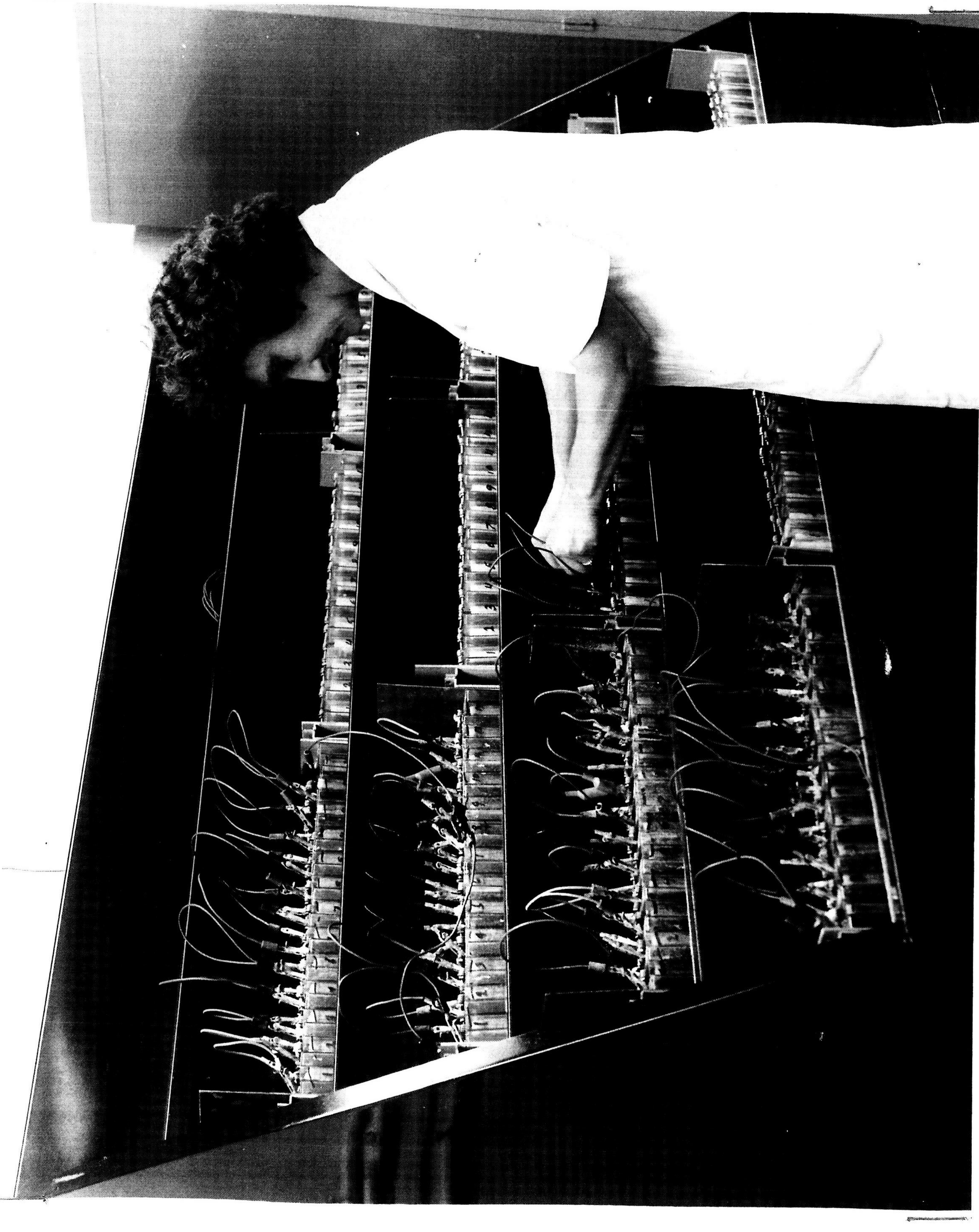
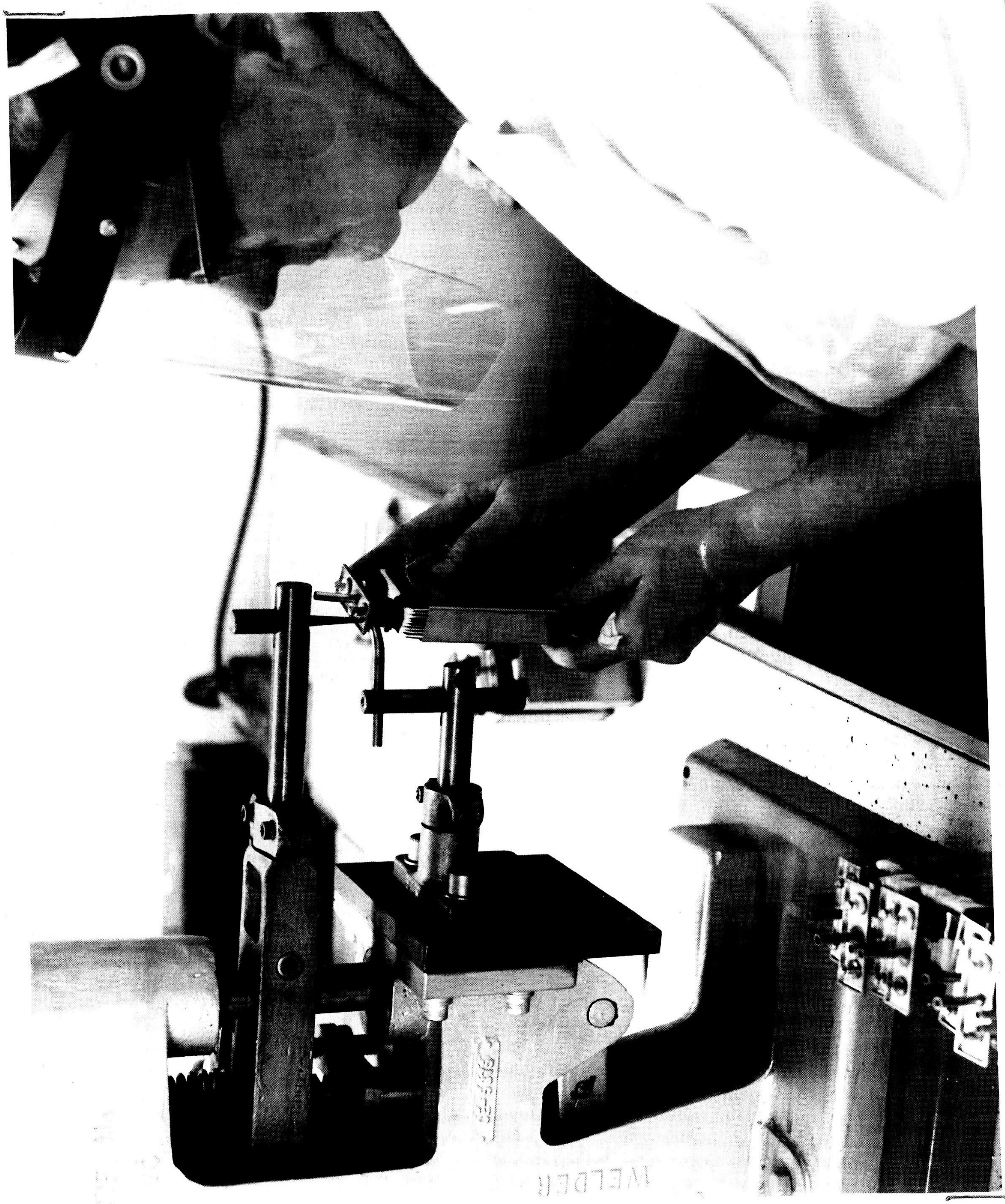


FIG. 5

FIG. 6



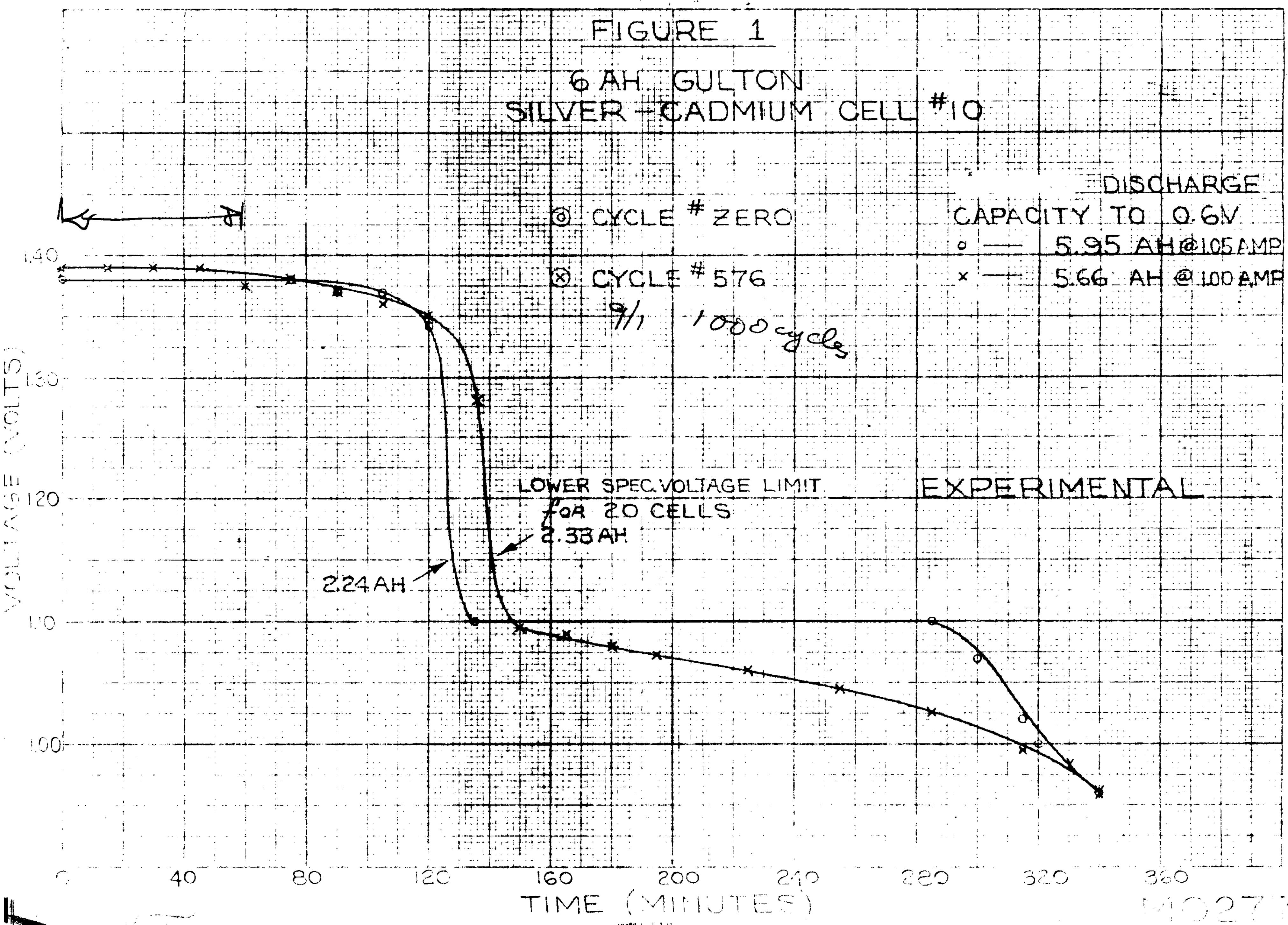


FIGURE 1
6 AH GULTON
SILVER-CADMIUM CELL #10
⊙ CYCLE # ZERO
⊗ CYCLE # 576
9/1 1000 cycles
DISCHARGE
CAPACITY TO 0.6V
o — 5.95 AH @1.05 AMP
x — 5.66 AH @1.00 AMP
LOWER SPEC. VOLTAGE LIMIT
FOR 20 CELLS
2.33 AH
2.24 AH
EXPERIMENTAL
1.40
1.30
1.20
1.10
1.00
VOLTAGE (VOLTS)
0
40
80
120
160
200
240
280
320
360
TIME (MINUTES)

M027

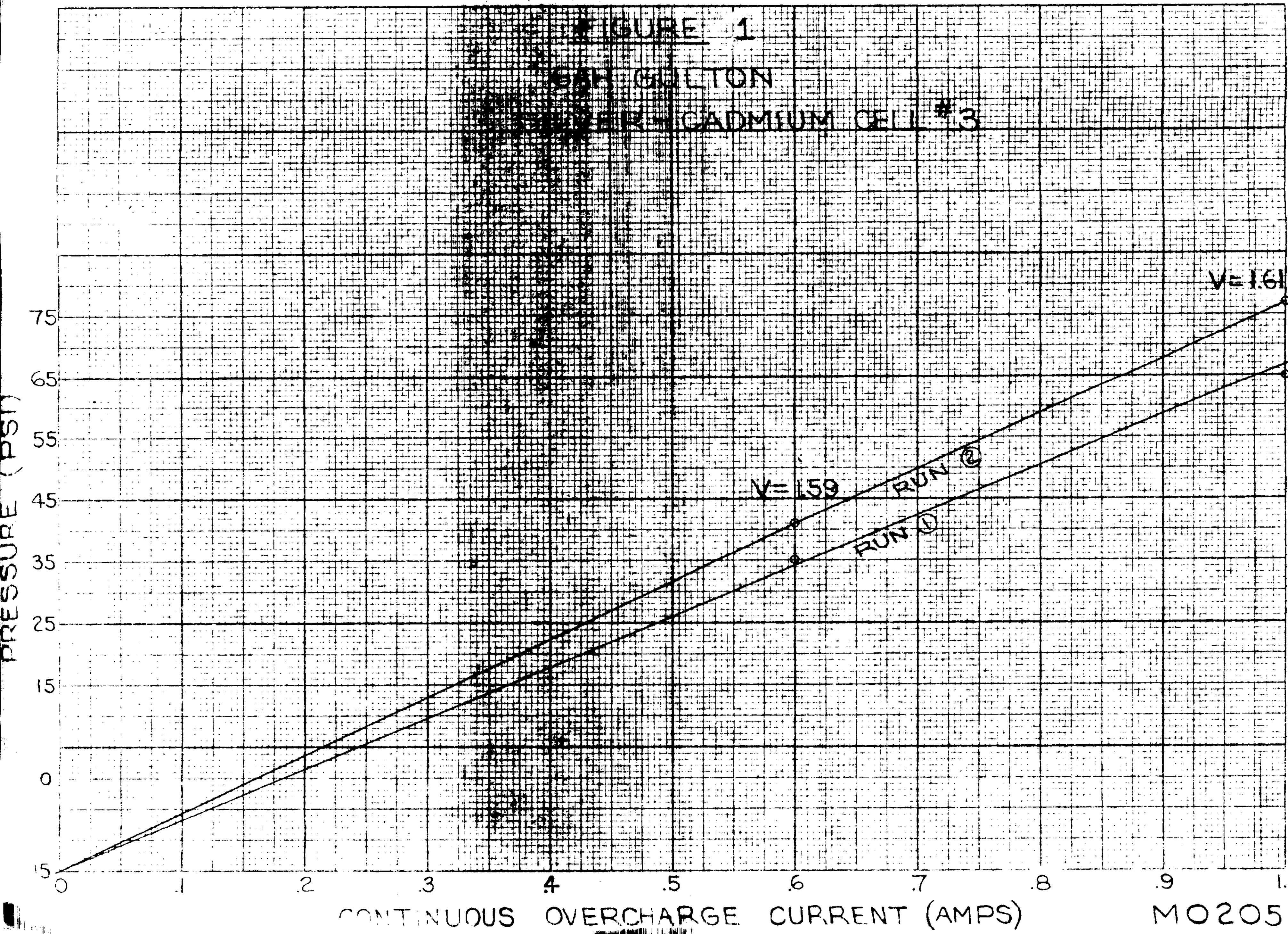
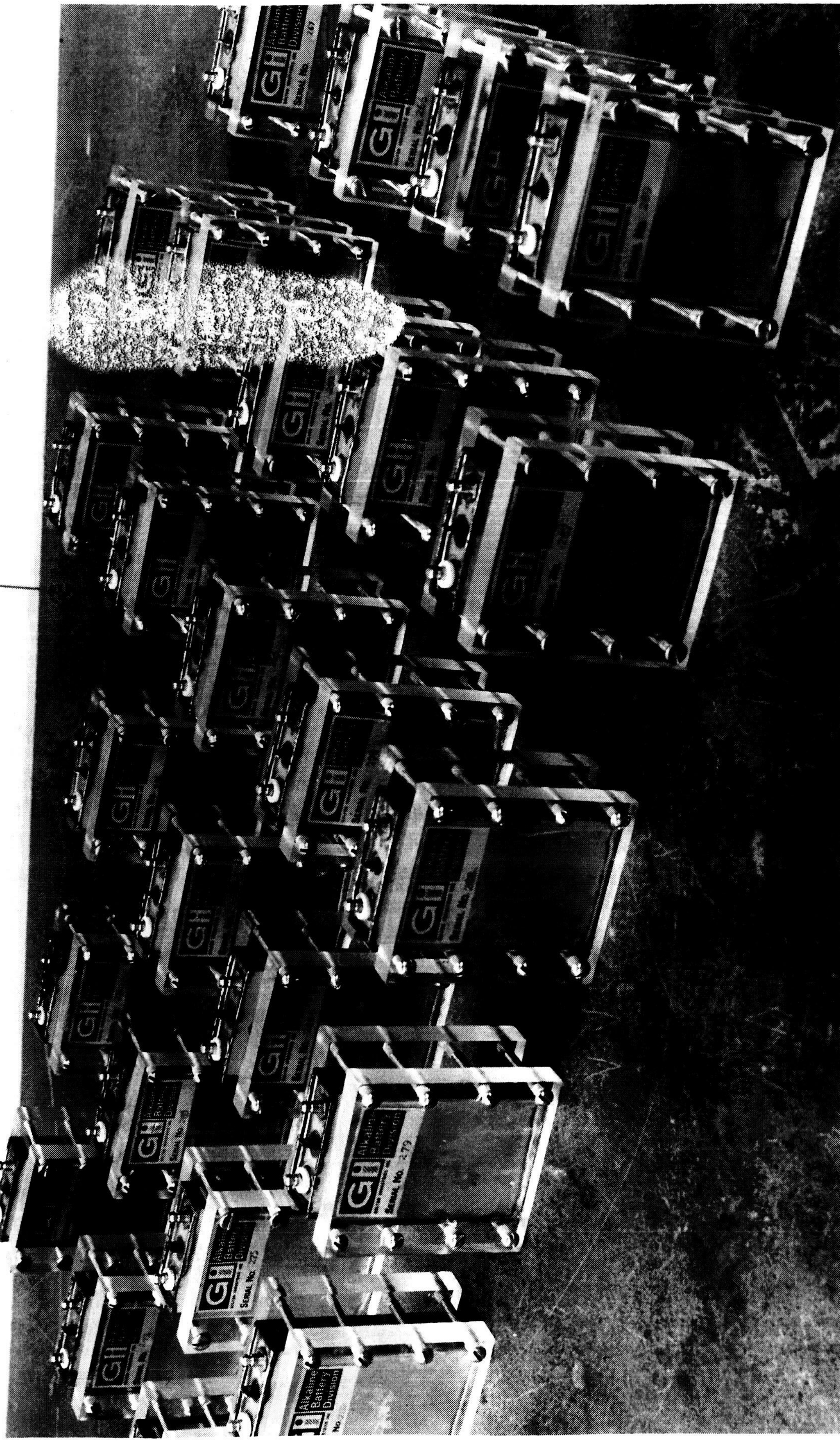
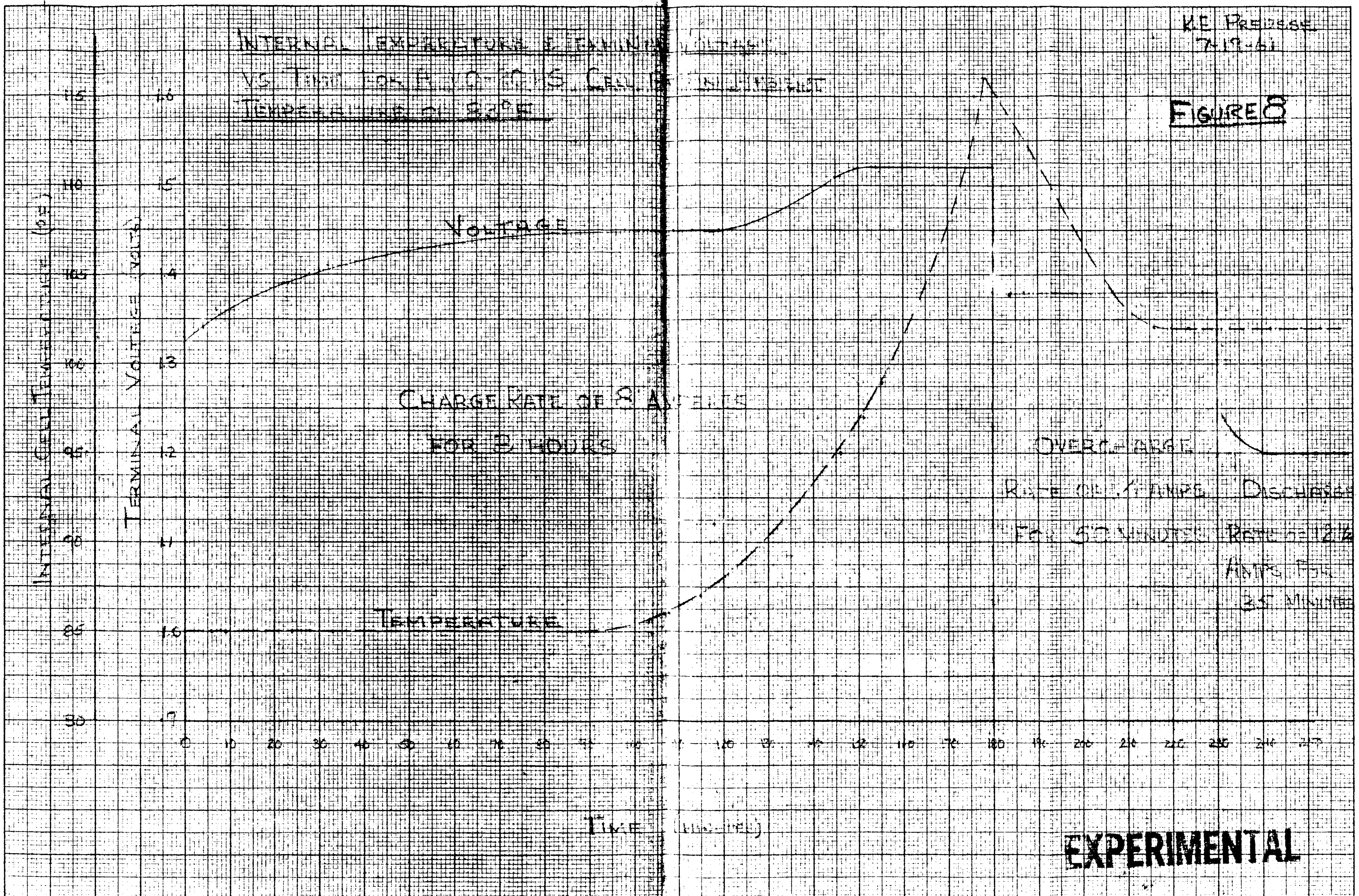


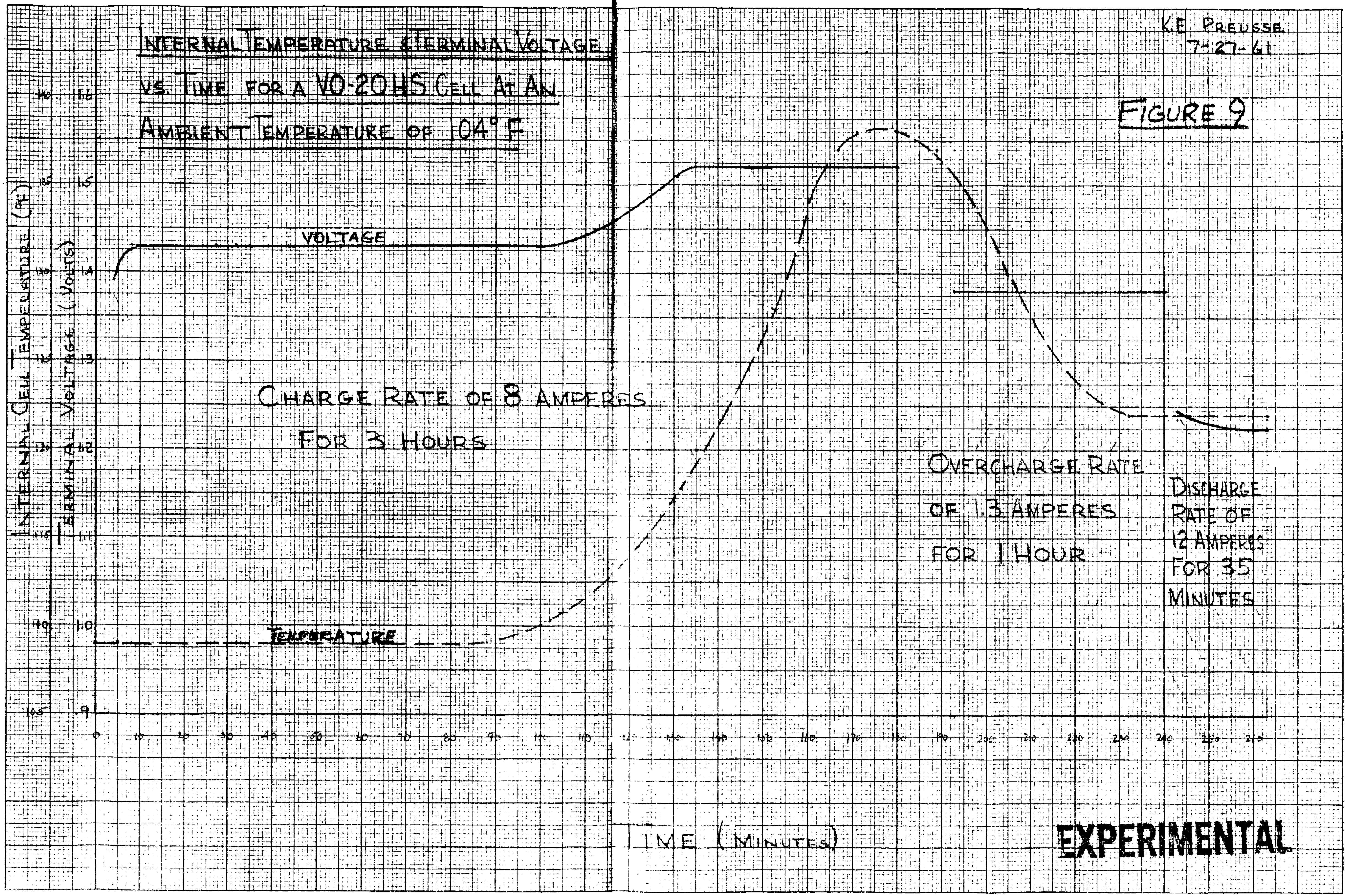
FIGURE 1
GULTON
CADMIUM CELL #3
V=1.61
V=1.59
RUN ②
RUN ①
75
65
55
45
35
25
15
0
15
PRESSURE (PSI)
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
CONTINUOUS OVERCHARGE CURRENT (AMPS)

MO205

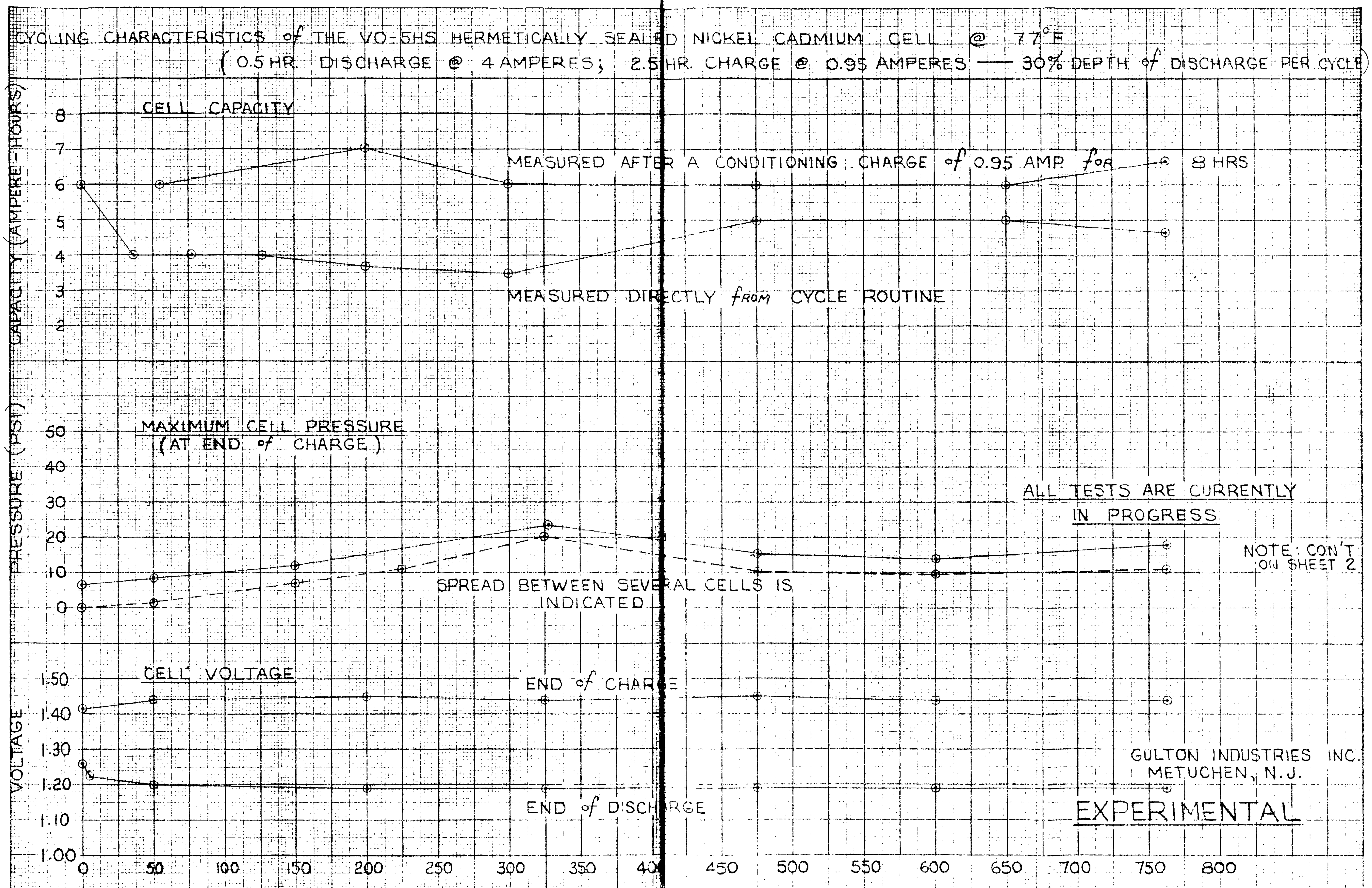
FIG. 7




Internal Temperature & Terminal Voltage
Figure 8
K.E. Preusse
7-19-61
Voltage
Temperature
Charge Rate of 8 Amperes
for 8 hours
Overcharge
Time
EXPERIMENTAL



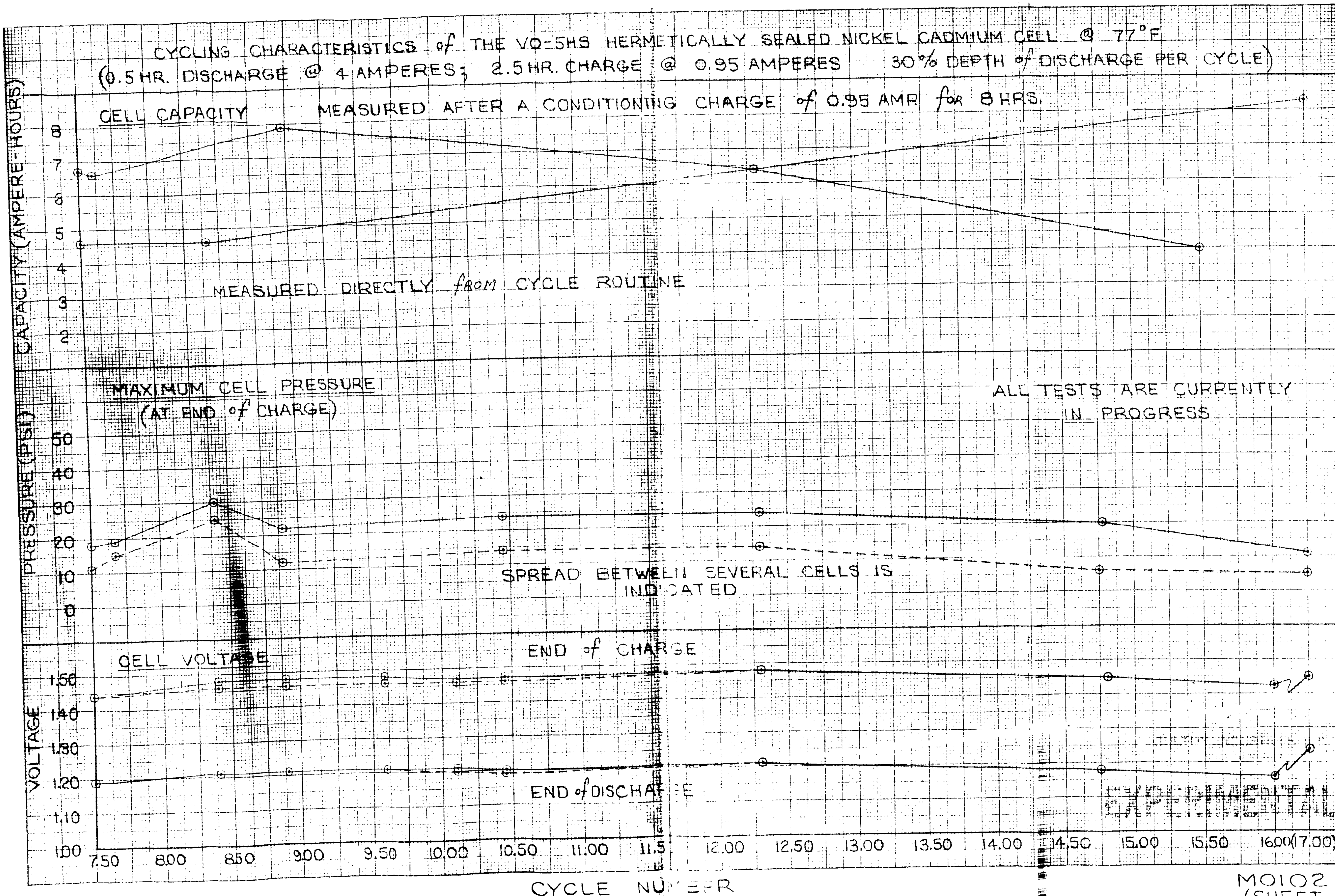
INTERNAL TEMPERATURE & TERMINAL VOLTAGE
VS. TIME FOR A VO-20HS CELL AT AN
AMBIENT TEMPERATURE OF 104° F
K.E. PREUSSE
7-27-61
FIGURE 9
VOLTAGE
TEMPERATURE
CHARGE RATE OF 8 AMPERES
FOR 3 HOURS
OVERCHARGE RATE
OF 1.3 AMPERES
FOR 1 HOUR
DISCHARGE
RATE OF
12 AMPERES
FOR 35
MINUTES
INTERNAL CELL TEMPERATURE (°F)
TERMINAL VOLTAGE (VOLTS)
TIME (MINUTES)
EXPERIMENTAL



MO102 A
SHEET 1

10 X 10 TO THE CM. KEUFFEL & ESSER CO. 359-14L MADE IN U.S.A.

EXHIBIT 22B



MO102 B
(SHEET 2)

10 X 10 TO THE CM. 359-14L
KEUFFEL & ESSER CO.

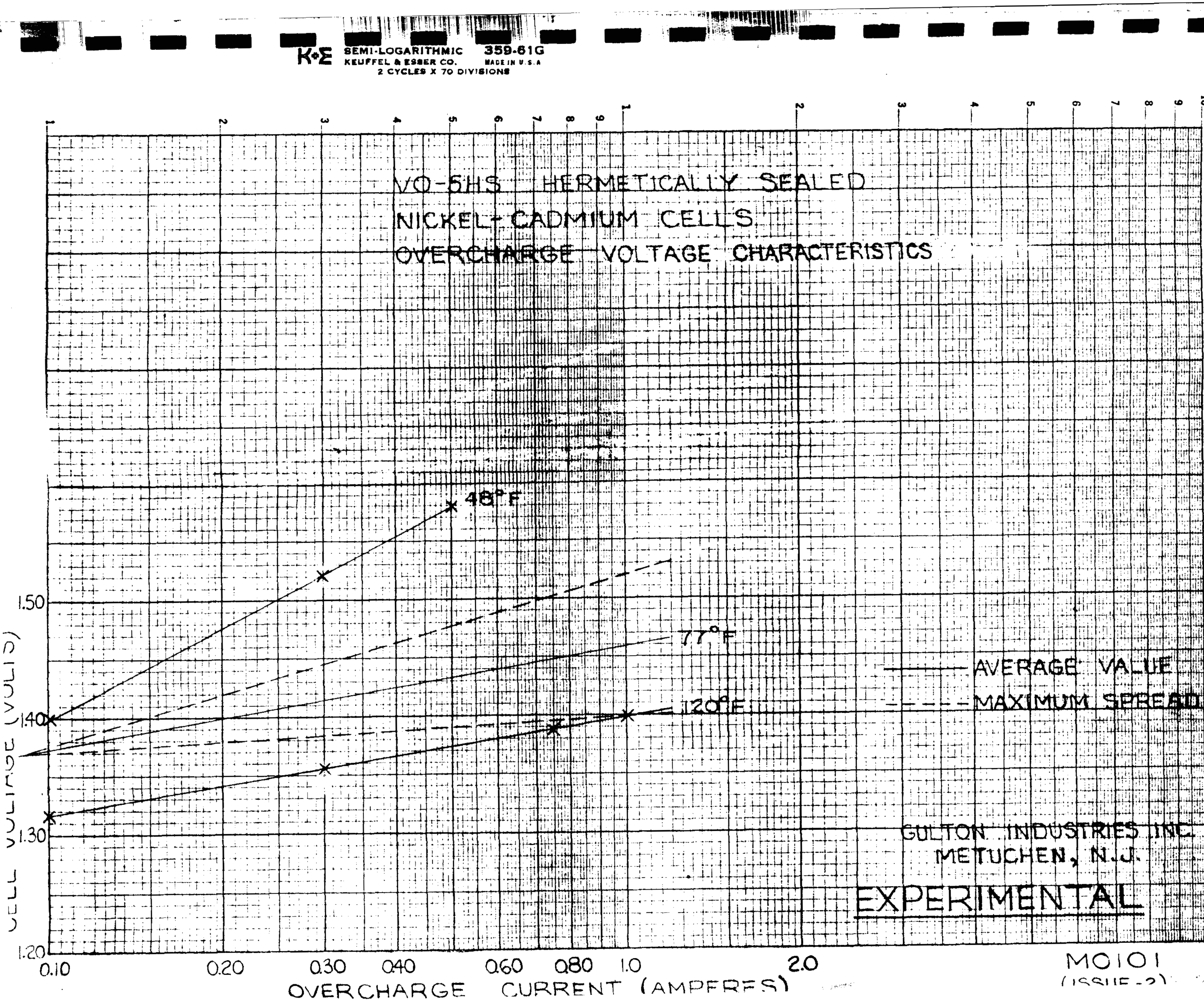


FIGURE 23

MO101
(ISSUE-2)